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An implementation of scanner ICC profile generator

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ABSTRACT

As the popularity of color peripheral devices grows, the problem of color inconsistency among color devices becomes more and more important. The ICC Profile, specified by the International Color Consortium (ICC), is a reasonable solution to achieve color consistency. This paper describes an implementation of automatic scanner ICC Profile generator. The generator mainly consists of a reference-file-parser, a target-image-analyzer, and a profile-parameters-evaluator. The reference-file-parser retrieves the XYZ and Lab values of color patches from the ANSI CGATS.5 compliance file. The RGB values of color patches are automatically extracted from the scanned ANSI IT8.7/2 target by the target-image-analyzer. Finally, the parameters that are required for profile construction are generated using the profile-parameters-evaluator. Based on the test of 4 types of scanners, the average $\Delta E^{*}ab$ of less than 3 is achieved..

Keywords: Scanner ICC Profile, Color Calibration

1. INTRODUCTION

As the popularity of color peripheral devices grows, the problem of color inconsistency among color devices becomes more and more important. The ICC Profile [1][2], specified by the International Color Consortium (ICC), is a reasonable solution to achieve color consistency. The major purpose of ICC Profiles is to characterize the color devices and to provide the color space transformation information between color devices and CIE standard. The CIE XYZ and CIE Lab are selected by the ICC as the intermediate color spaces and are called the Profile Connection Space (PCS). The relation between PCS and ICC Profiles is shown in figure 1.

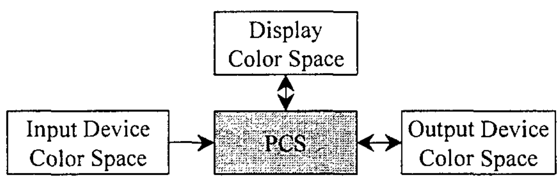

Figure 1. The relation between PCS and ICC profiles

There are two color space transfer models are defined for the device ICC profiles. One is called three-component matrix-based model and another is called N-component Look-Up-Table (LUT)-based model. In general, each model suits for different kinds of devices. For the scanner ICC profile, both the two models can be used and are implemented in our scanner ICC profile generator. The two models are described as follows.

Three-component matrix-based model: The three-component matrix-based model mainly consists of a red Tone-Reproduction-Curve (TRC), a green TRC, a blue TRC, a red colorant, a green colorant, and a blue colorant. Where the RGB TRCs are used to linearize the tone curves of RGB and the RGB colorants are used to translate the linearized RGB values to XYZ values. For the given RGB values retrieved from the scanner, the RGB values can be translated to XYZ by using the following equations.

$$linear_r = TRC_r\left[Device_r\right] \tag{1}$$

$$linear_g = TRC_g\left[Device_g\right] \tag{2}$$

$$linear_b = TRC_b\left[Device_b\right] \tag{3}$$

$$\begin{bmatrix} PCS_X \\ PCS_Y \\ PCS_Z \end{bmatrix} = \begin{bmatrix} redColorant_X & greenColorant_X & blueColorant_X \\ redColorant_Y & greenColorant_Y & blueColorant_Y \\ redColorant_Z & greenColorant_Z & blueColorant_Z \end{bmatrix} \begin{bmatrix} linear_r \\ linear_g \\ linear_b \end{bmatrix} \tag{4}$$

Where the $Device_r$, $Device_g$, $Device_b$ are the RGB values got from the scanner, the $linear_r$, $linear_g$, $linear_b$ are the linearized RGB values, and the PCS_x , PCS_y , PCS_z are the corresponding XYZ values of the RGB values got from the scanner. To use the three-component matrix-based model for color space transformation, the RGB values of scanner are firstly mapped to the linear version using the individual TRC. After that, the relative XYZ values of the linearized RGB values can be calculated by multiplying the RGB colorant with the linearized RGB values.

N-component LUT-based model: The N-component LUT-based model used in the scanner ICC profile consists of RGB TRCs, a three-dimensional LUT, and three linearization curves. The RGB TRCs are used to linearize the input channels. The three-dimensional LUT is used to translate the color space from scanner color space to CIE Lab. The three linearization curves are used to linearize the output channels. The N-component LUT-based model for scanner ICC profile is shown in the figure 2.

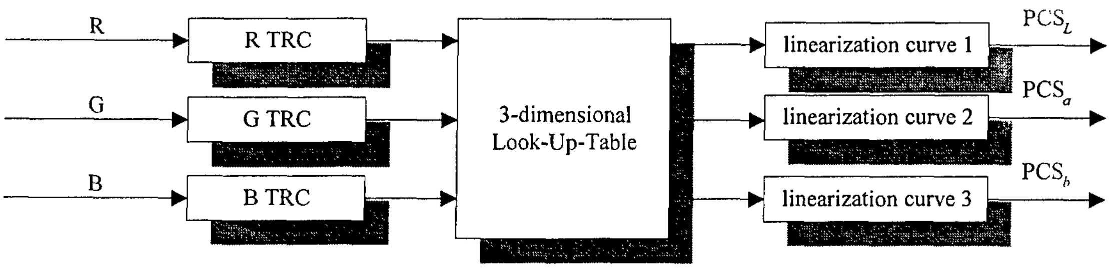

Figure 2. The N-component LUT-based model for scanner ICC profile

In this paper, two models described above are implemented in the proposed scanner ICC profile generator. Except that, the generation process of scanner ICC profile is also be automated by introducing the reference-file-parser and the target-image-analyzer. The rest of this paper is organized as follows. The system architecture of scanner ICC profile generator is given in section 2. The implementation details of reference file parser, target image analyzer, and profile parameter evaluator are described in section 3. The experimental results are listed in section 4. Finally, the conclusions are given in section 5.

2. SYSTEM ARCHITECTURE OF THE SCANNER ICC PROFILE GENERATOR

To generate the scanner ICC profile, the differences between the scanner color space and CIE standard must be discovered. The IT8.7/1 [3] and IT8.7/2 [4] targets are the standard color targets defined by ANSI and contains variety color patches that can be used to analyze the color characteristics of scanner. Figure 3 shows the layout of IT8.7/1 and IT8.7/2. In the bottom of the target, a gray-bar with 24 patches is given to characterize the tone representation of input devices. The 12 rows by 22 columns color patches are given in the top of the target can be use to characterize the color features of input devices.

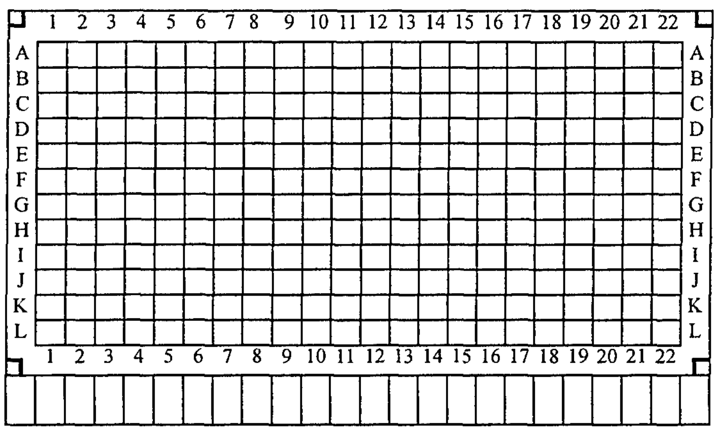

Figure 3. The layout of IT8.7/1 or IT8.7/2

By using the IT8.7/1 or IT8.7/2 target for generating the scanner ICC profile, the RGB values of color patches from scanned target and the XYZ values of color patches from colorimetric are required. Once the RGB and XYZ values of the color patches are acquired, the parameters required for constructing the scanner ICC profile can be evaluated. The system architecture of the scanner ICC Profile generator is shown in the following.

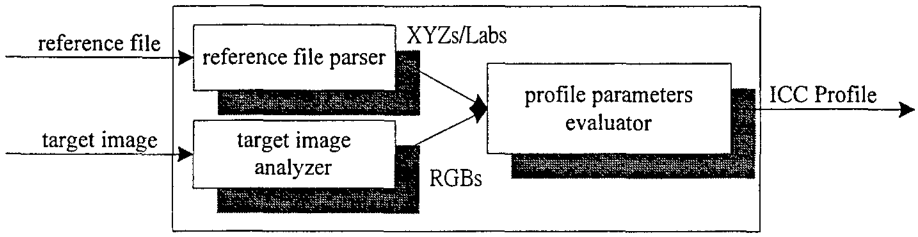

Figure 4. The system architecture of scanner ICC profile generator

Where the reference file is a ANSI CGATS.5 [5] compliance file for storing the measured XYZ and Lab values of color patches of the IT8.7/1 or IT8.7/2 target and the target image is an image of the IT8.7/1 or IT8.7/2 target scanned by the testing scanner. The generator mainly consists of a reference-file-parser, a target-image-analyzer, and a profile-parameters-evaluator. The reference-file-parser is used to retrieve the XYZ and Lab values of color patches from reference file. The target-image-analyzer is used to extract the RGB values of color patches from the target image. Once the XYZ, Lab, and RGB values of color patches are acquired, the parameters required for three-component matrix-based model and the N-component LUT-based model can be evaluated by the profile-parameters-evaluator.

3. IMPLEMENTATION OF THE SCANNER ICC PROFILE GENERATOR

In this section, we will present the implementation of scanner ICC profile generator more detail. The reference-file-parser, target-image-analyzer, and profile-parameters-evaluator are described in the following.

3.1. reference-file-parser

The reference-file-parser is used to retrieve the XYZ and Lab values of color patches from the ANSI CGATS5 compliance file. The ANSI CGATS5 standard specifies a methodology for taking spectral measurements and making colorimetric computations as well as defines a data exchange format for storing the measured color data. Figure 5 shows an example of ANSI CGATS5 compliance file.

```
IT8.7/2
ORIGINATOR          "S010/OES/ITRI"
DESCRIPTOR          "Color Target (Illumination=D50   ObserverAngle=2)"
CREATED             "4/16/2000"
NUMBER_OF_FIELDS       7
BEGIN_DATA_FORMAT
SampleName   XYZ_X   XYZ_Y   XYZ_Z   LAB_L   LAB_A   LAB_B
END_DATA_FORMAT
NUMBER_OF_SETS     288
BEGIN_DATA
A1           4.40    3.76    2.65    22.88   11.15   3.44
A2           5.15    3.58    2.14    22.25   23.51   6.75
                 ...
Dmax         0.47    0.57    0.47    5.14    -3.32   -0.06
END_DATA
```

Figure 5. An example of ANSI CGATS5 compliance file

The algorithm for retrieving the reference file is presented as follows.

The algorithm of reference-file-analyzer

(1) File validity checking: The first 7 characters in the file must be the "IT8.7/1" or "IT8.7/2".

(2) Data format retrieving: The arrangement information of XYZ and Lab values are encapsulated by the "BEGIN_DATA_FORMAT" and "END_DATA_FORMAT" keywords. Before retrieving the measured data of target, the arrangement information of XYZ and Lab values must be known.

(3) Measured data retrieving: The XYZ and Lab values encapsulated by the "BEGIN_DATA" and "END_DATA" keywords can be retrieved using the arrangement information of the XYZ and Lab values.

(4) Data validity checking: To ensure the retrieved XYZ and Lab values are the correct XYZ and Lab values of IT8.7/1 or IT8.7/2 target. The XYZ and Lab values can be checked using the characteristics of the target. Such as, the XYZ values of the leftest patch of gray-bar in the target must larger than of the rightest patch of gray-bar in the target.

3.2. target-image-analyzer

The target-image-analyzer is used to extract the RGB values of color patches from the IT8.7/1 or IT8.7/2 target image automatically. To extract the RGB values in the scanned target image, a target-positioning algorithm is proposed to determine the four-corners of the frame in the outer of the target image. After the four-corners of the frame are determined, the position of color patches can be derived by the posture of the color patches in the frame and the RGB values of color patches can be retrieved by averaging the RGB values of pixels inside the color patches. The target-positioning algorithm used to find the four-corners of the frame of the target image is listed in the following.

The target-positioning algorithm

(1) Determine the position of the left and right borders of the frame: Firstly, the middle row of the target image is picked. To find the position of the left border in the middle row, the pixels are checked by border verifier from the most left pixel to the right until the border pixel is found. To find the position of the right border in the middle row, the pixels are checked by border verifier from the most right pixel to the left until the border pixel is found.

(2) Determine the upper-left and upper-right corners of the frame: The left and right border pixels in the upper row of middle row can be found by checking the pixels in the top and near to the border pixels of the middle row with border verifier. By using the same procedure upgoing, all the left and right border pixels in the top of the left and right border pixels of the middle row can be found. As a result, the upper-left and upper-right corners of the frame can be found.

(3) Determine the lower-left and lower-right corners of the frame: The left and right border pixels in the lower row of middle row can be found by checking the pixels in the bottom and near to the border pixels of the middle row with border verifier. By using the same procedure downgoing, all the left and right border pixels in the bottom of the left and right border pixels of the middle row can be found. As a result, the lower-left and lower-right corners of the frame can be found.

The illustration of the target-positioning algorithm is shown in figure 6.

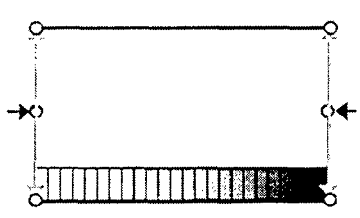

Figure 6. The process of the target-positioning algorithm

To recognize the border pixel, a border verifier is developed. The border verifier verifies the border pixels by using the border conditions and border weighting function. The border conditions and border weighting function are given in table 1. In step 1 of the target-positioning algorithm only the border conditions are used. In step 2 and step 3 of the target-positioning algorithm both the border conditions and border weighting function are used.

Table 1. The border condition table

border conditions	*Dl*	*Dr*	*Dlr*	*Wa*	*Wb*
(White, Black, Gray)	*>EdgeThr*	*>EdgeThr*	*>EdgeThr*	*PrivilegeW*3*	*Dl+Dr+Dlr*
(Gray, Black, Gray)	*>EdgeThr*	*>EdgeThr*	*<EdgeThr*	*PrivilegeW*2*	*Dl+Dr*
(Black, Black, Gray)	*<EdgeThr*	*>EdgeThr*	*>EdgeThr*	*PrivilegeW*1*	*Dlr*
(Gray, Black, White)	*>EdgeThr*	*>EdgeThr*	*>EdgeThr*	*PrivilegeW*3*	*Dl+Dr+Dlr*
(Gray, Black, Black)	*>EdgeThr*	*<EdgeThr*	*>EdgeThr*	*PrivilegeW*1*	*Dlr*
Others				*0*	*0*

The border conditions are observed from the relations of the border pixels and their neighboring pixels and denoted as the form of (L, B, R). The L represents the pixel on the left of the border, the B represents the border pixel, and the R represents the pixel on the right of the border. The observed border conditions are: *(White, Black, Gray)*, *(Gray, Black, Gray)*, *(Black, Black, Gray)*, *(Gray, Black, White)*, and *(Gray, Black, Black)*. For a given pixel, the *Dl*, *Dr*, *Dlr*, and *EdgeThr* are used to check if the pixel matches any border conditions. Where the *Dl* is the difference between the given pixel and its left neighboring pixel, the *Dr* is the difference between the given pixel and its right neighboring pixel, and the *Dlr* is the difference between the left neighboring pixel and the right neighboring pixel of the given pixel. The *EdgeThr* is a threshold and is used to determine the relation of *LB*, *BR*, and *LR*.

The border weighting function *BWF* is defined to determine a best border pixel from plural possibly border pixels and listed in the following.

$$BWF = W_a + W_b \tag{5}$$

Where the W_a is observed from the difference between the border conditions and the W_b is observed from the difference between the border pixels belong to the same border condition. That is, the W_a is used to find the pixels of better border condition and the W_b is used to find the better border pixel of the same border condition. The *PrivilegeW* in table 1 is used to distinguish the effect of W_a and W_b and must larger than the maximum of all combination of *Dl+Dr+Dlr*.

3.3. profile-parameters-evaluator

The profile-parameters-evaluator is used to generate the parameters of the three-component matrix-based model and N-component LUT-based model for the scanner ICC Profile. The flowcharts of two models used for scanner ICC Profile are shown in figure 7 and figure 8.

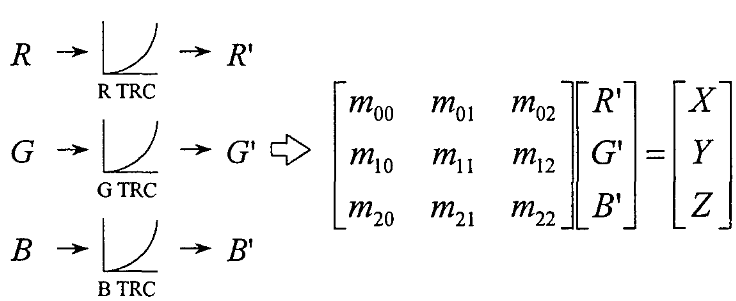

Figure 7. The three-component matrix-based model for scanner ICC Profile

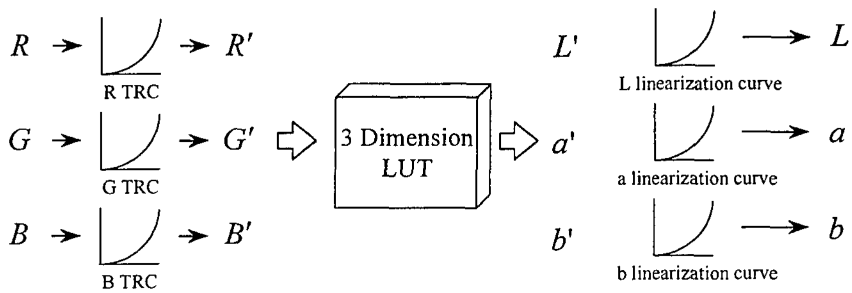

Figure 8. The N-component LUT-based model for scanner ICC Profile

For the three-component matrix-based model, the RGB TRCs and the RGB to XYZ transfer matrix (RGB colorants) must be generated. For the N-component LUT-based model, the RGB TRCs, the RGB to Lab LUT, and the linearization curves of Lab must be generated. The RGB TRCs used in the three-component matrix-based model are the same as the ones used in the N-component LUT-based model. The linearization curves of Lab are not used to linearize the Lab in this paper. That is, the L'a'b' values are equal to the Lab values. The generation of the RGB TRCs, the RGB to XYZ transfer matrix, and the RGB to Lab LUT are described as follows.

The generation of RGB TRCs: Figure 9 illustrates the generation method of the RGB TRCs in the implementation. Where the Y value and RGB values comes from the gray-bar of the target. The RGB TRCs are used to pull the RGB tone curves to fit the Y tone curve. By using the Y value and RGB values, the tone reproduction curve of RGB channels can be generated and can be used to linearize the RGB channels.

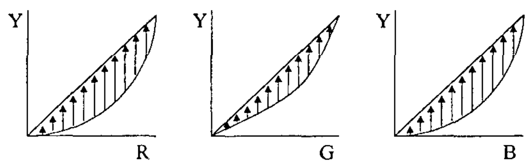

Figure 9. The generation of RGB TRCs

The generation of the RGB to XYZ transfer matrix: In this paper, the regression model [6-9] is used to create the RGB to XYZ transfer matrix. The color patches located in the column 1 to 19 of row A to L and the gray-scale 1 to 22 are used as the input of regression model. Before the RGB can be used, the RGB must be linearized using the RGB TRCs. For a set of linearized RGB and XYZ data {R(l), G(l), B(l), X(l), Y(l), Z(l): l=1 to n}, the RGB to XYZ transfer matrix M can be derived using the following equations.

$$\begin{aligned} C(l) &= \{c_0(l), c_1(l), c_2(l)\} \\ &= \{R(l), G(l), B(l)\}; \end{aligned} \tag{6}$$

$$\begin{aligned} A_{3\times3} &= \{a(i,j) : i = 0 \sim 2, j = 0 \sim 2\}, \\ a(i,j) &= \sum_{l=1}^{n} c_i(l) \cdot c_j(l); \end{aligned} \tag{7}$$

$$\begin{aligned} B_{3\times3} &= \{b(i,j) : i = 0 \sim 2, j = 0 \sim 2\}, \\ b(i,0) &= \sum_{l=1}^{n} X(l) \cdot c_i(l), \\ b(i,1) &= \sum_{l=1}^{n} Y(l) \cdot c_i(l), \\ b(i,2) &= \sum_{l=1}^{n} Z(l) \cdot c_i(l); \end{aligned} \tag{8}$$

$$M_{3\times3}^{T} = A_{3\times3}^{-1} \cdot B_{3\times3} \tag{9}$$

The generation of the RGB to Lab LUT: The generation process of the RGB to Lab LUT is shown in figure 10. In figure 10, the input RGB values with the size of 33x33x33 are firstly linearized by the RGB TRCs. Secondly, a 3×14 matrix is used to translate the linearized RGB values to XYZ values. Finally, the Lab values of $33 \times 33 \times 33$ LUT can be obtained by translating the XYZ values to Lab values using the XYZ to Lab function.

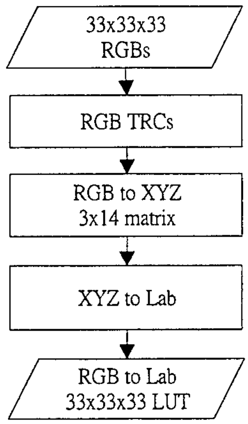

Figure 10. The generation process of the RGB to Lab LUT

The matrix used here is similar to the one presented in the [6] and is generated using the regression model. The generation process of the matrix is similar to the generation process of the RGB to XYZ transfer matrix. But sets the $C(l) = \{c_0(l), c_1(l), c_2(l), c_3(l), c_4(l), c_5(l), c_6(l), c_7(l), c_8(l), c_9(l), c_{10}(l), c_{11}(l), c_{12}(l), c_{13}(l)\} = \{1, R(l), G(l), B(l), R(l)^2, G(l)^2, B(l)^2, R(l)\times G(l), G(l)\times B(l), R(l)\times B(l), R(l)^3, G(l)^3, B(l)^3, R(l)\times G(l)\times B(l)\}$, the size of matrix A is 14 x 14, and the size of matrix B is 14×3.

4. EXPERIMENTAL RESULTS

To demonstrate the performance of the scanner ICC Profile generator, a scanner ICC Profile evaluator is developed here to evaluate the performance of scanner ICC profile. The flowchart of the scanner ICC Profile evaluator is shown in the following.

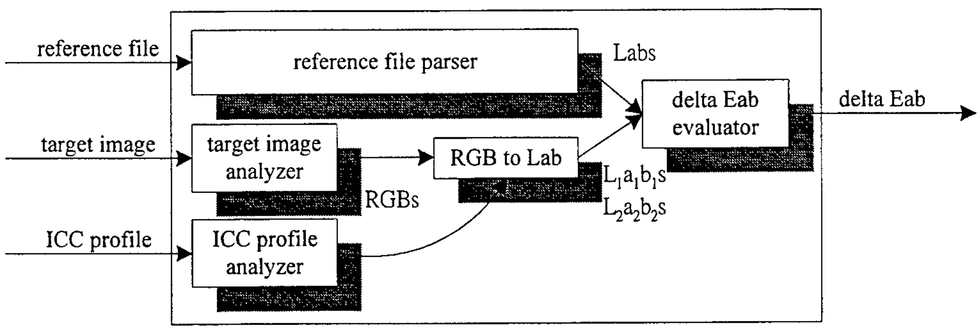

Figure 11. the flowchart of scanner ICC profile evaluator

The scanner ICC profile evaluator mainly consists of a reference-file-parser, a target-image-analyzer, an ICC-profile-analyzer, a RGB-to-Lab function, and a delta-Eab-evaluator. Where the reference-file-parser and the target image-analyzer are the same as of the scanner ICC profile generator. The ICC-profile-analyzer is used to retrieve the RGB TRCs, the RGB to XYZ transfer matrix, and the RGB to Lab LUT from the ICC profile. The RGB to Lab function translates the RGB values extracted from the target-image to two sets of Lab values for the three-component matrix-based model and N-component

LUT-based model, respectively. Where, a Trilinear interpolation scheme [10] is applied for the translation of RGB to Lab using the N-component LUT-based model. After the two sets of Lab values acquired, the ΔE^*abs of the two models can be evaluated by the following equation.

$$\Delta E^*ab = \sqrt{(L-L_1)^2 + (a-a_1)^2 + (b-b_1)^2} \tag{10}$$

In the experiments, a Kodak IT8.7/2 target produced in the march 1998 and four kinds of scanners - the Acer Prisa 620U, the HP SJ4200U, the Mustek 1200U, and the Umax Astra 2100U - are used to evaluate the performance of scanner ICC profile generator. In the experimental process, the ICC profiles of testing scanners are generated using the scanner ICC profile generator. Next, the same reference file and target images used to generate the ICC profiles are also used to evaluate the performance of the generated scanner ICC profile. The average ΔE^*abs of tested scanners using the three-component matrix-based model and N-component LUT-based model are given in Table 2 and Table 3, respectively.

Table 2. The average ΔE^*abs of four types of scanners using three-component matrix-based model

Scanner	ΔE^*ab
Acer Prisa 620U	3.48
HP SJ4200C	3.36
Mustek 1200U	4.09
Umax Astra 2100U	3.88

Table 3. The average ΔE^*abs of four types of scanners using N-component LUT-based model

Scanner	ΔE^*ab
Acer Prisa 620U	2.86
HP SJ4200C	2.87
Mustek 1200U	2.85
Umax Astra 2100U	2.94

From the above tables, we can see the average ΔE^*abs of tested scanners are almost less than 4 in three-component matrix-based model and the average ΔE^*abs of tested scanners are less than 3 in N-component LUT-based model.

5. CONCLUSIONS

In this paper, an implementation of scanner ICC profile generator is described. A reference-file-parser and a target-image-analyzer are developed to automate the retrieving of the XYZ and Lab values from the reference file and the extraction of the RGB values of color patches from the target image, respectively. Two regression models are used to implement the three-component matrix-based model and N-component LUT-based model. The experimental results show the average ΔE^*abs of generated ICC profiles for both models are small.

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